

We claim:

- 1           1.       A method for detecting one or more objects belonging to the same  
2 object class comprising the steps of:  
3           a). receiving a video sequence comprised of a plurality of image frames;  
4           b). applying one or more classifiers to detect components of objects in an  
5 image frame in the video sequence;  
6           c). computing a confidence score based in part on the response from the  
7 one or more component detectors;  
8           d). repeating steps b). and c). to detect components of objects belonging  
9 to the same object class in additional images frames in the video sequence; and  
10          e). accumulating confidence scores from the component detectors to  
11 determine if an object is detected.
- 1           2.       The method of claim 1 wherein if accumulated confidence scores  
2 indicate high confidence of a presence of an object, the method further  
3 comprising the step of:  
4           identifying the detected components to be an object of a particular type.
- 1           3.       The method of claim 1 wherein the object class is a vehicle.
- 1           4.       The method of claim 1 further comprising the step of:  
2 if an object is detected, outputting a detection signal and object position.
- 1           5.       The method of claim 2 further comprising the steps of:  
2           testing geometry constraints on a spatial arrangement of detected  
3 components in an image; and  
4           applying whole-appearance classifiers an image patch that contains the  
5 detected components and which is aligned according to the position of the  
6 detected components.

1           6.       The method of claim 5 wherein the geometry constraints are  
2 derived from camera parameters.

1           7.       The method of claim 5 wherein the geometry constraints are  
2 derived from object size.

1           8.       The method of claim 5 wherein the geometry constraints are  
2 derived from a location of an object appearance in the image.

1           9.       The method of claim 5 wherein the whole appearance classifiers  
2 detect entire or partial object appearance, the entire or partial object appearance  
3 being aligned according to positioning of at least two components.

1           10.      The method of claim 1 wherein the component classifiers include  
2 classifiers for detecting components at multiple scales.

1           11.      The method of claim 1 wherein component classifiers are defined  
2 by discriminant features and decision rules which are learned through boosted  
3 training.

1           12.      The method of claim 11 wherein the discriminant features include  
2 corners.

1           13.      The method of claim 11 wherein the discriminant features include  
2 horizontal edges.

1           14.      The method of claim 11 wherein the discriminant features include  
2 vertical edges.

1           15.      The method of claim 11 wherein the discriminant features include  
2 horizontal stripes.

1           16.     The method of claim 11 wherein the discriminant features include  
2 vertical stripes.

1           17.     The method of claim 11 wherein the discriminant features include  
2 diagonal stripes.

1           18.     The method of claim 11 further comprising the step of:  
2 performing an online adaptation to adapt a classifier structure to an online  
3 pattern.

1           19.     The method of claim 18 wherein the step of performing an online  
2 adaptation further comprises the step of:  
3 applying a dynamic switching strategy to direct the detector to take  
4 appropriate weak classifiers as discriminants according to auxiliary information  
5 about the online pattern.

1           20.     The method of claim 2 wherein the one or more classifiers include  
2 overlapping component classifiers.

1           21.     The method of claim 20 wherein the overlapping component  
2 classifiers comprises four corners representing a rear profile of a vehicle.

1           22.     The method of claim 20 wherein the overlapping component  
2 classifiers comprises four corners representing a frontal profile of a vehicle.

1           23.     The method of claim 20 wherein the overlapping component  
2 classifiers comprises four corners representing a side profile of a vehicle.

1           24.     The method of claim 21 wherein one of the overlapping component  
2 classifiers detects the bottom left corner of a vehicle.

1           25.     The method of claim 21 wherein one of the overlapping component  
2 classifiers detects the bottom right corner of a vehicle.

1           26.     The method of claim 21 wherein one of the overlapping component  
2 classifiers detects the top left corner of a vehicle.

1           27.     The method of claim 21 wherein one of the overlapping component  
2 classifiers detects the top right corner of a vehicle.

1           28.     The method of claim 21 wherein positioning of the four corners of  
2 the rear profile for a vehicle differ for different classes of vehicles.

1           29.     The method of claim 28 wherein a class of vehicle includes  
2 sedans.

1           30.     The method of claim 28 wherein a class of vehicle includes sports  
2 utility vehicles.

1           31.     The method of claim 28 wherein a class of vehicle includes vans.

1           32.     The method of claim 28 wherein a class of vehicle includes tractor  
2 trailers.

1           33.     The method of claim 28 wherein a class of vehicle includes trucks.

1           34.     The method of claim 21 wherein a distance between any two  
2 corners of the vehicle is constrained.

1           35.     The method of claim 34 wherein the constraint between any two  
2 corners of the vehicle is scaled based on a distance between the vehicle and a  
3 camera capturing the video sequence and camera parameters.

1           36.     The method of claim 35 wherein an image pyramid of multiple  
2 resolutions is used to detect objects of size  $2 \times x$ ,  $4 \times x$  and so on with the classifier  
3 for the size  $x$ .

1           37.     The method of claim 1 wherein the accumulated confidence scores  
2 are inferred from confidence scores across multiple frames using a recursive  
3 filter.

1           38.     The method of claim 37 wherein when the accumulated  
2 confidence score is a linear combination of the confidence scores of multiple  
3 component classifiers and the whole-appearance classifiers.

1           39.     The method of claim 38 wherein when the confidence score for a  
2 principal component classifier is sufficiently high, the confidence score of the  
3 remaining component classifiers and the whole-appearance classifier are  
4 computed.

1           40.     The method of claim 2 wherein if an object is detected the method  
2 comprising the step of:  
3 tracking the object over subsequent image frames.

1           41.     The method of claim 40 wherein the step of tracking the object  
2 further comprises the step of:  
3 restricting an area of search in each subsequent image frame based on  
4 the location of the object in a current image frame.

1           42.     The method of claim 40 wherein the step of tracking the object  
2 further comprises the step of:  
3 determining the optimal classifier scale based on a distance between the  
4 object and a camera detecting the object and camera parameters.

1           43.     The method of claim 1 wherein the confidence scores of  
2     component classifiers are computed in a coarse to fine framework.

1           44.     The method of claim 1 wherein detection is performed on an  
2     image pyramid of multiple resolutions.

1           45.     The method of claim 1 wherein an object class includes  
2     pedestrians.

1           46.     The method of claim 1 wherein an object class includes bicycles.

1           47.     The method of claim 1 wherein an object class includes  
2     motorcycles.

1           48.     The method of claim 1 wherein object class includes different types  
2     of traffic signs.

3  
1           49.     A system for detection and tracking an object comprising:  
2             a camera for capturing a video sequence comprised of a plurality of image  
3     frames;  
4             a processor for receiving the video sequence and analyzing each image  
5     frame to determine if an object is detected, said processor applying one or more  
6     classifiers to detect components of objects in each image frame and computing a  
7     confidence score based on the response from the one or more component  
8     detectors and the result of additional validation; and  
9             a database for storing the one or more classifiers and object training  
10    samples

- 1           50.     The method of claim 49 wherein the object class is a vehicle.
- 1           51.     The method of claim 49 wherein the object class is a pedestrian.
- 1           52.     The method of claim 49 wherein the object class is a bicycle.
- 1           53.     The method of claim 49 wherein the object class is a motorbike.
- 1           54.     The method of claim 49 wherein the object class includes different  
2 types of traffic signs.
- 1           55.     The system of claim 49 wherein the detected components are  
2 determined to be an object if the confidence scores are high.
- 1           56.     The system of claim 55 wherein if an object is detected, the  
2 processor outputs a warning signal.
- 1           57.     The system of claim 49 further comprising :  
2 a display for displaying the video sequence.
- 1           58.     The system of claim 49 wherein the processor further comprises:  
2 means for testing geometry constraints on a spatial arrangement of  
3 detected components in an image; and  
4 means for applying whole-appearance classifiers an image patch that  
5 contains the detected components and which is aligned according to the position  
6 of the detected components.
- 1           59.     The system of claim 58 wherein the geometry constraints are  
2 derived from camera parameters.

1           60.     The system of claim 58 wherein the geometry constraints are  
2     derived from object size.

1           61.     The system of claim 58 wherein the geometry constraints are  
2     derived from a location of an object appearance in the image.

1           62.     The system of claim 58 wherein the whole appearance classifiers  
2     detect entire or partial object appearance, the entire or partial object appearance  
3     being aligned according to positioning of at least two components.

1           63.     The system of claim 49 wherein the component classifiers include  
2     classifiers for detecting components at multiple scales.

1           64.     The system of claim 49 wherein component classifiers are defined  
2     by discriminant features and decision rules which are learned through boosted  
3     training.

1           65.     The system of claim 64 wherein the discriminant features include  
2     corners.

1           66.     The system of claim 64 wherein the discriminant features include  
2     horizontal edges.

1           67.     The system of claim 64 wherein the discriminant features include  
2     vertical edges.

1           68.     The system of claim 64 wherein the discriminant features include  
2     horizontal stripes.

1           69.     The system of claim 64 wherein the discriminant features include  
2     vertical stripes.



1           70.     The system of claim 64 wherein the discriminant features include  
2 diagonal stripes.

1           71.     The system of claim 64 further comprising the step of:  
2 performing an online adaptation to adapt a classifier structure to an online  
3 pattern.

1           72.     The system of claim 71 wherein the step of performing an online  
2 adaptation further comprises the step of:  
3 applying a dynamic switching strategy to direct the detector to take  
4 appropriate weak classifiers as discriminants according to auxiliary information  
5 about the online pattern.

1           73.     The system of claim 49 wherein the one or more classifiers include  
2 overlapping component classifiers.

1           74.     The system of claim 73 wherein the overlapping component  
2 classifiers comprises four corners representing a rear profile of a vehicle.

1           75.     The system of claim 74 wherein one of the overlapping component  
2 classifiers detects the bottom left corner of a vehicle.

1           76.     The system of claim 74 wherein one of the overlapping component  
2 classifiers detects the bottom right corner of a vehicle.

1           77.     The system of claim 74 wherein one of the overlapping component  
2 classifiers detects the top left corner of a vehicle.

1           78.     The system of claim 74 wherein one of the overlapping component  
2 classifiers detects the top right corner of a vehicle.

1           79.     The system of claim 74 wherein positioning of the four corners of  
2     the rear profile for a vehicle differ for different classes of vehicles.

1           80.     The system of claim 79 wherein a class of vehicle includes sedans.

1           81.     The system of claim 79 wherein a class of vehicle includes sports  
2     utility vehicles.

1           82.     The system of claim 79 wherein a class of vehicle includes vans.

1           83.     The system of claim 79 wherein a class of vehicle includes tractor  
2     trailers.

1           84.     The system of claim 74 wherein a distance between any two  
2     corners of the vehicle is constrained.

1           85.     The system of claim 84 wherein the constraint between any two  
2     corners of the vehicle is scaled based on a distance between the vehicle and a  
3     camera capturing the video sequence as well as camera parameters.

1           86.     The system of claim 85 wherein an image pyramid of multiple  
2     resolutions is used to detect objects of size  $2 \times x$ ,  $4 \times x$  and so on with the classifier  
3     for the size  $x$ .

1           87.     The system of claim 49 wherein the accumulated confidence  
2     scores is inferred from confidence scores across multiple frames using a  
3     recursive filter.

1           88.     The system of claim 87 wherein when the accumulated confidence  
2     score is a linear combination of the confidence scores of multiple component  
3     classifiers and the whole-appearance classifiers.

1           89.     The system of claim 87 wherein when the confidence score for a  
2     principal component classifier is sufficiently high, the confidence score of the  
3     remaining component classifiers and the whole-appearance classifier are  
4     computed.

1           90.     The system of claim 49 wherein the processor comprises:  
2             means for tracking a detected object over subsequent image frames.

1           91.     The system of claim 90 wherein tracking means further comprises:  
2             means for restricting an area of search in each subsequent image frame  
3     based on the location of the object in a current image frame.

1           92.     The system of claim 90 wherein the tracking means further  
2     comprises:  
3             means for determining the optimal classifier scale based on a distance  
4     between the object and a camera.detecting the object and camera parameters.

          93.     The system of claim 49 wherein the confidence scores of  
component classifiers are computed in a coarse to fine framework

1           94.     The system of claim 49 wherein detection and tracking is  
2     performed on an image pyramid of multiple resolutions.

1           95.     A method for tracking one or more objects depicted in a video  
2     sequence comprising:  
3             receiving a video sequence comprised of a plurality of image frames;  
4             detecting an object to be tracked in one of the image frames;  
5             computing one or more appearance trajectories based on the position of  
6     the tracked object to estimate the direction in which the tracked object is  
7     traveling; and

8           determining if the object is the tracked object based on the appearance  
9   trajectory.

1           96.     The method of claim 95 wherein said step of determining if the  
2   object is the tracked object further comprises the steps of:  
3           applying one or more classifiers to the computed appearance trajectory;  
4           computing a confidence score for the computed appearance trajectory;  
5   and  
6           determining the object to be the tracked object if the confidence score is  
7   high.

1           97.     The method of claim 95 wherein the computation of the  
2   appearance trajectory considers physically well-founded motion constraints.

1           98.     The method of claim 95 wherein the trajectories are computed by  
2   accumulating detection results over multiple frames.

1           99.     The method of claim 98 wherein the computed appearance  
2   trajectory determines changes in position, scale, location and aspect conditions  
3   in consecutive frames.

1           100.    The method of claim 95 wherein the tracked object is a vehicle.

1           101.    The method of claim 95 wherein the tracked object is a pedestrian.

1           102.    The method of claim 95 wherein the tracked object is a bicycle.

1           103.    The method of claim 95 wherein the tracked object is a motorbike.

1           104.    The method of claim 95 wherein the tracked object includes  
2   different types of traffic signs.